BRIDGING THE GAP: ATTEMPTING TO INCREASE LANDSCAPE CONNECTIVITY USING WILDLIFE CORRIDORS IN THE LOST PINES ECOLOGICAL AREA OF TEXAS

by

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ABSTRACT

Infrastructure development continues to increase to keep pace with the growth and expansion of human populations. Core infrastructure, such as roads, results in wildlife mortality and continued fragmentation of available habitat. Artificial wildlife corridors are a potential solution to mitigating wildlife-motorist collisions and maintaining habitat connectivity. Such structures are components toward conservation stewardship of both species and landscapes. The Lost Pines region is home to the endemic, and endangered, Houston Toad. These structures serve as mitigation efforts to allow the Houston Toad and other wildlife a safe passage among habitat patches despite barriers to dispersal.

Highway 290 in Bastrop County bisects critical habitat of the endangered Houston Toad. Wildlife corridors have now been installed at locations based on previous data indicating areas of high wildlife traffic. Our study applies a suite of monitoring techniques to determine usage of artificial wildlife corridors along section the roadway. Monitoring techniques include camera trapping and wildlife mortality surveys (walking and driving). In order to determine usage of these corridors, camera traps were placed at the opening of each culvert. Wildlife mortality surveys along the roadway seek to determine areas of high density, and examine mortality densities post-installation of corridors. Preliminary analysis compared wildlife mortality observations found in the construction area during pre-construction and during construction. These results show no

difference in mortality observations between treatments. However, there is a significant difference in observations between survey methods (walking vs driving). Currently, there are no camera trap detections of wildlife utilizing the crossing structures at each location.

CHAPTER 1

INTRODUCTION

As human populations continue to grow, so does the need for infrastructure development. These developments not only include residential areas but linear infrastructure in the form of roadway systems as well. The installation of new roadway systems, or modification of existing roadways, are generally a positive addition in the day to day lives of humans in developed areas. However, the same may not be true for the wildlife found in those same areas. The installation of new roadway systems in previously undeveloped areas generates disturbances that can penetrate into the surrounding wildlife communities and affect many aspects of the habitat (Wilcox and Murphy 1985; Reed et al. 1996; Forman and Alexander 1998; Coffin 2007; Lopez et al. 2010; Ree et al. 2011). These intrusions into isolated habitats increase negative interactions between wildlife and humans, create barriers to movement, attract animals to roadways to forage for available food sources, and cause habitat fragmentation. These effects of habitat modification caused by building linear infrastructure have been identified as some of the main reasons for wildlife species decline (Vitousek et al. 1997; Laurance et al. 2009).

Since the identification of numerous problems associated with roadway systems, efforts to understand impacts on the surrounding landscape continue to grow. As a result, there has been an increase in management strategies and mitigation efforts that attempt to resolve these impacts so that they benefit both wildlife and humans. Implementation of wildlife crossing structures (WCS) to increase landscape connectivity is a growing management strategy that is becoming more prevalent in areas with high animal traffic, an increased number of wildlife-vehicle collisions (WVC), and critical habitat units that are home to endangered or threatened species (Tischendorf and Fahrig 2000). These corridors, or passage systems, vary in structure, size, and implementation. Drainage culverts, fencing, and bridges are often used to create an underpass allowing safe passage for wildlife across the landscape (McCollister and Manen 2010; Gagnon et al. 2011; Mateus et al. 2011). By utilizing structures already in use or available, such as drainage culverts or bridges, transportation planners are able to better implement these strategies in future or current roadway systems to reduce not only wildlife mortality, but also human mortality and injury caused by WVC (Hughes et al. 1996).

Plans to increase landscape connectivity using wildlife crossings are being implemented in a wide range of environments, from Banff National Park in Canada (Alexander and Waters 2000) to the Lake Jackson Ecopassage in Florida (Aresco 2005; 2006), to serve a variety of species. Here, I examine a roadway system, U.S. Highway 290, in northeastern Bastrop County, Texas (Fig. 1 and 2). This area is within the Lost Pines ecological area and is home to the federally endangered Houston Toad (*Bufo houstonensis*), the state threated Texas horned lizard (*Phrynosoma cornutum*), and timber rattlesnake (*Crotalus horridus*). Other wildlife, such as white-tailed deer (*Odocoileus virginianus*), coyote (*Canis latrans*), bobcat (*Lynx rufus*), and a wide variety of birds, reptiles, and amphibians, are also found within the Lost Pines ecological area. Soils of this ecological area are primarily sandy loams and the dominant canopy trees are loblolly pines (*Pinus taeida)* and several species of oaks (*Quercus* spp.) (Campbell 2003). U.S. Highway 290 is a highly trafficked roadway system that effectively bisects this region and the critical habitat of the Houston Toad. The Houston Toad was the first amphibian to be federally listed as an endangered species (Gottschalk 1970). Historically, it was found in Harris county, where it was first described, as well as surrounding coastal areas (Allison and Wilkins 2001). However, it has since been extirpated from most of its range (Sanders 1953; Peterson et al. 2004) and is now found within the Lost Pines ecological area, Blackland Prairie, and Post Oak Savanah of Texas, with more limited distribution in the woodlands north of the coastal plain. Declines of these populations have been thought to be a result of habitat fragmentation and urbanization. These declines have restricted the Houston Toad further even within its historical range (Forstner et al. 2007). The development of continuous roadway systems throughout one of the remaining critical habitat areas, Bastrop, Texas, increase habitat fragmentation. However, with the implementation of mitigation strategies, such as WCS, we have the ability to reconnect fragmented landscapes in areas that would most benefit the Houston Toad.

U.S. Highway 290 is currently undergoing expansion from a four lane, undivided highway, to a four lane divided highway. Monitoring this roadway was done pre-construction in an attempt to determine areas of high wildlife mortality, as well as areas with high wildlife usage (Forstner et al. 2008). These data were used to determine sites for WCS to increase connectivity and protect movement of the Houston Toad as well as reduce wildlife-vehicle collisions. These WCS were installed at two locations along a 12.58 km stretch of U.S. Highway 290. Culvert systems in conjunction with bridges (Fig. 3) were utilized to create underpass crossing structures at both pre-determined locations (Forstner et al. 2008). As stated, the target species of these culvert systems is the Houston Toad. However, these crossing structures are large enough to accommodate large and small mammals. Reptiles, and other amphibians can benefit from their use as well.

Installing these culvert underpasses as part of WCS has the potential to benefit multiple species within the area by increasing connectivity of these landscapes and providing a way for wildlife to safely traverse the landscape. We also have the ability to reduce WVCs which are costly both financially and in human life (Hughes et al. 1996).

I intend to examine the effectiveness of WCSs currently installed at two locations along a roadway system in the Lost Pines ecological area. The primary objective of this study is to determine usage of the culvert systems by native wildlife by monitoring these systems, as well as other culvert systems along the roadways. This study will serve as a baseline for the recently installed corridor systems and determine the overall short and long term usage by wildlife. I also intend to examine roadkill along the stretch of roadway to determine areas of high wildlife mortality using three different survey methods: 1) driving surveys with video recording devices, 2) traditional driving surveys, 3) walking surveys. These will also be compared to determine variation in detections between the methods. Monitoring this roadway section will provide valuable data to determine if wildlife is in fact utilizing these WCSs and if so, is there a decrease in wildlife mortality as a result of wildlife usage.

CHAPTER 2

DETERMINING USAGE OF WILDLIFE CORRIDOR SYSTEMS IN THE LOST PINES ECOLOGICAL AREA OF TEXAS

INTRODUCTION

The development of areas that were once untouched is an increasing occurrence as human populations continue to rise. While this benefits humans economically, it creates negative issues in the wildlife populations found in these areas. Habitat fragmentation that occurs when roadways are constructed and put in use represents one of the main adverse impacts of such infrastructure on wildlife populations and ecological systems (Wilcox and Murphy 1985; Saunders et al. 1991; Forman and Alexander 1998; Ng et al. 2004). Not only do these roadway systems create habitat fragmentation, they also serve as a movement barrier for animals traversing the landscape. These barriers can disrupt annual migration patterns and lead to genetic differentiation further impacting populations of wildlife (Reh and Seitz 1990; Trombulak and Frissell 1999). We also see interactions between wildlife and motorists. These WVCs tend to be negative and can result in wildlife and/or human mortality or injury, as well as cost to human property (Reed et al. 1982; Conover et al. 1995; Hughes et al. 1996; Foreman and Alexander 1998). To regulatory agencies, these negative interactions and the impacts on humans can be a driving force to investigate methods and strategies to alleviate and resolve these issues. Creating a system that would allow for the safe travel of wildlife across a roadway system has the potential to benefit humans by reducing mortality and property damage while also protecting wildlife and the habitats in which they are found.

Wildlife corridor systems can provide a valuable mode for connecting fragmented habitat units as well as providing safe passage for animals traversing the landscape. These can target a single species in regards to size of the crossing structure, or serve as a system that can be used by a wide range of animal species. The use of existing structures, such as culverts, allows the implementation of management strategies desired by regulatory agencies, as well as reducing implementation costs, because the corridor is already completed and only needs minor maintenance (Brudin 2003). These culvert drainages are readily available to regulatory agencies to develop, and can serve as a cost effective mitigation technique that increases both motorist and wildlife safety in the area.

In this study, existing culverts have been modified and two large culvert drainage systems located under roadway bridges have been installed to create wildlife underpasses. In cooperation with the Texas Department of Transportation (TXDOT) these corridors were placed as part of a road expansion project (Fig. 8). The location of the WCS were determined based on roadkill densities, wildlife usage determined by camera traps, and locations of known breeding areas of the Houston Toad. These areas were identified in a previous monitoring effort conducted along the roadway before construction of the expansion project (Forstner et al. 2008).

Determining usage of these WCSs is an important part of evaluating their effectiveness in both the long term and short term (Gagnon et al. 2011). As a result, we potentially can replicate these methods in other areas of the state to benefit both a target species or general wildlife in the area. Here I examine the usage of two currently installed WCSs, as well as six existing smaller culvert systems, by deploying camera traps. Data collection of species movement patterns and behavior by use of game cameras is a common practice used by biologists (O'Brien et al. 2011). They permit remote monitoring of species without impacting their natural behaviors (O'Brien et al. 2011). Utilizing camera traps at these crossing locations has the potential to provide crucial data in understanding whether animals are utilizing these crossing structures, and if so, what species. The use of cameras will serve two purposes. The first is determining if the completed culvert systems along the U.S. Highway 290 roadway system are being utilized. The second purpose is to examine the correlation between usage of these systems and wildlife mortality.

MATERIALS AND METHODS

Study site.—Monitoring efforts occurred on a 12.58 km stretch of U.S. Highway 290 (Fig. 1 and 2) North-East of Bastrop, Texas, between State Highway 21 and FM 2336, which is undergoing an expansion. The roadway system was divided into two treatments, Construction Treatment (CT) and No Construction Treatment (NCT). Monitoring of this section of roadway occurred bi-weekly from January 2016 to May 2017.

Monitoring Design.—Two monitoring techniques were utilized for this study: camera traps and track pads. For camera traps, a total of 11 Reconyx Hyperfire Pro PC900 game cameras were placed at each of the 8 locations along the roadway (Fig. 3). Three locations, including the two newly installed underpasses, consisted of two cameras placed on either side of the roadway, thus covering the extent of the corridor system. The remaining locations consisted of one camera deployed because the areas are inaccessible due to private property restrictions. The two WCSs were deemed Goodwater (GW) and

Midsprings (MS) (Fig. 4). Cameras were placed at the opening of each of these WCSs to monitor usage of the installed underpasses. Camera maintenance, consisting of battery and memory card changes, occurred monthly. Captures were documented by location, species, and time of day for all sites. These data were used to compare usage at each of the 8 locations within the study site.

In addition to camera traps, track pads were also deployed in order to monitor the usage of the installed WCSs. The track pads, 2.5 m long, will span the width of the WCSs and will be (McCollister and Manen 2010; Ng et al. 2004). Two track pads were installed (Fig. 5) at the North and South ends of both WCSs. Track pads were checked biweekly, and captures by species were determined by presence or absence. The track pads were raked after each survey to remove previous captures.

RESULTS

Camera trap monitoring efforts from January 2016 to May 2017 resulted in a total of 848 observations within the study area. Out of the eleven camera trap locations three resulted in highest observations; G (n=200), D (n=199), and E (n=179) (Fig. 6). The total number of observations at location D (Goodwater WCS) were heavily influenced by feral hogs (n=156) (Fig. 7). Remaining observations at location D consisted of raccoon, opossum, deer, coyote, and domestic cat. However, no animals were observed utilizing the WCS in these observations. Location GWS (Goodwater WCS) is at the southern entrance to the crossing structure and three animals (cat and dog) were observed utilizing the WCS (Fig. 8). Although there were no observations of animals utilizing the WCS from the Northern entrance (location D) based on camera observations, animals were found to utilize this WCS based on track pad observations. Feral hog tracks were found at the northern track pad at the Goodwater WCS (Fig. 9 and 10) but not at the southern. Raccoon, opossum, domestic cat and dog tracks were also observed at both the southern and northern trackpads at the Goodwater locations. No tracks were observed for herpetofaunal species at both Goodwater locations. However, species of anurans were often observed at these locations. Herpetofauna observed include; southern leopard frog (*Rana sphenocephala*), northern cricket frog (*Acris crepitans*), red-eared slider (*Trachemys scripta elegans*, mortality observation), and diamond-backed watersnake (*Nerodia rhombifer*).

Two camera traps (MSS and B) were placed at the Midsprings WCS location. Camera trap MSS which is located at the southern entrance to the WCS resulted in a total of 33 observations. Photographic observations included raccoon (n=28), heron (n=3), and feral hog (n=2) (Fig. 11). Of the thirty-three observations, three instances of raccoons utilizing the crossing structures were found (Fig. 12). Camera trap B, located at the northern entrance of the WCS, resulted in a total of 23 observations (Fig. 13). Twenty-one of the twenty-three observations were determined to be feral hog, with the remaining two observations being coyotes. There were no observations of animals utilizing the WCS at the B camera trap location.

Remaining observations at camera locations within the study site included bobcat, feral hog, coyote, possum, as well as other small mammal and herpetofaunal species. Both locations G and E resulted in the highest and third highest overall species observations. Observations at location G were comprised of armadillo (n=96), cow (72), bobcat (n=7), raccoon (n=20), opossum (n=2) (Fig. 14). Location G resulted in the highest number of animals utilizing the culvert (Fig. 15) to cross beneath the highway (n=84). Location E had the third highest observations (n=179). However, there were no observations of animals using the preexisting culvert at this location. All observations at this location were of animals utilizing the Right Of Way (ROW) along the highway. Feral hogs were observed most frequently (n=103) followed by white-tailed deer (n=50). Remaining observations were comprised of smaller mammal species; armadillo, domestic cat, coyote, domestic dog, opossum, and raccoon (Fig. 16). When examining camera observations post construction I found similar number of observations per month from the completion of the WCS (December 2016) to the end of the study (May 2017). However, observations increased significantly from February to March from 50 to 168 respectively (Fig. 17). Number of observations in April (n = 74) and May (n = 30) were reduced and resembled previous months' observations.

DISCUSSION

From these observational data, I found an abundance of animals utilizing this stretch of highway, either along the ROW or utilizing existing and the recently installed WCS. Camera location G which was placed at the Piney Creek location in the No Construction area was found to have the greatest number of observations of wildlife utilizing the existing culvert for movement beneath the highway. This existing culvert is a large box culvert at a drainage in the No Construction treatment. I observed small species of mammals such as raccoon and opossum, using this as a movement structure. Large mammals (cows) and mesocarnivores (bobcat) were also observed utilizing this structure to traverse between habitats separated by U.S. Highway 290. When examining camera observations post construction/installation I found a significant increase in observations in March 2017 compared to previous and following months. This increased number of observations was a result of higher observations of feral hogs within the Construction treatment.

Overall few species were observed transiting the recently installed WCS at the two locations. Camera traps placed at the Midsprings location only provided three instances of animals (raccoon) utilizing the crossing structures. The Goodwater WCS observed similar results with three instances of animals entering the crossings structures; domestic dog and cat. Although the camera traps placed at these WCS did not result in high detections of animal usage of the structures the track pads did capture animal movements beneath the WCS. By using these trackpads, I was able to determine the presence/absence of animals transiting the WCS despite lack of camera trap observations. At the Midsprings WCS location an abundance of anurans was observed at the structure. This location connects a drainage basin that flows beneath the highway and now exposes several small springs. This creates a semi-aquatic environment allowing anurans to congregate and persist. The presence of water created an issue with the trackpads beneath the structures. I found multiple instances of the trackpads fully submerged, and as a result, not being able to monitor the trackpads for movement. However, when trackpads were not submerged I found presence of meso-mammals utilizing the Midsprings WCS. These mammals were primarily raccoon and opossum, as well as domestic cat. I also had the same issue at the Goodwater WCS location with the northern culvert. After rain events this area acted as a drainage impoundment which as a result, submerged the trackpad. Track pads at the Goodwater WCS did result in the presence of meso-mammals such as opossum, raccoon, domestic dog, and domestic cat. The northern track pad at the Goodwater WCS was also found to have tracks from feral hogs. These animals were also observed in the resulting camera trap images. However, no tracks were found at the southern trackpad location. This shows that larger species of mammals are beginning to familiarize themselves with the WCS at this location but have not fully traversed the length of the crossing structure.

Comparatively, few studies stated explicitly when their monitoring began after WCS were installed (Van der Ree et al. 2007). This makes it difficult to compare our current observations of WCS utilization post-installation to previous studies. However, several instances show that animals began to use the structures installed within a short time frame. Our monitoring efforts observed meso-mammals such as raccoons utilizing these structures upon completion. This similar occurrence was seen where the Mountain Pygmy possum (*Burramys parvus*) was observed utilizing a WCS in Australia two weeks after the installation was completed (Mansergh and Scotts 1989). Van der Ree's literature assessment documents this observation as the earliest usage of a WCS by an animal. These observations coincide with our observations of meso-mammals utilizing the WCS shortly after they were installed. Larger animals such as white-tailed deer, feral hogs, coyotes, etc. may have a longer acclimation time. White-tailed deer have also been documented using preexisting culverts along a highway system (McCollister and van Manen 2010). They also showed that white-tailed deer usage was 6.7 times greater after the new WCS were installed and completed. These WCS were monitored both pre and post installation to determine usage. However, there are no data about how quickly the animals began to traverse these WCS.

Our monitoring efforts both during construction and post-installation of these WCS will create a better understanding of the usage timeline, post-installation. Extensive monitoring post-installation is imperative in understanding the immediate and long term impact the WCSs have on the wildlife. The Lake Jackson Ecopassage, a permeant drift fence and underpass crossing structure, was monitored extensively for 2.5 years post-installation and showed that mortality rates dropped after the installation of fencing and crossing structures (11.9 DOR/km/day to 0.09 DOR/km/day) (Aresco 2005). However, in our case, drift fence or funnel fencing was not installed to direct animals to the WCS. This fencing forces animals to utilize the WCS that has been installed which can further decrease instances of DOR along the roadway. These studies, along with others, show that animals vary in their acclimation and usage of WCS post-installation and construction. Since the completion of the WCS in December 2016 I have three camera trap instances and presence absence trackpad observations of animals utilizing the WCS. However, I have also observed multiple occurrences of animals utilizing the WCS before they were fully completed. These results align with studies referred to previously showing some animal species begin to utilize the WCS as soon as they are installed, and in this case, before fully completed.

Although I found few observations of animals utilizing the two WCS recently installed, I found an abundance of animals utilizing the existing large box culvert at camera location G. The usage of this pre-existing structure can serve as a proxy for animals using culvert systems to traverse beneath highways. As mentioned previously, animals, such as white-tailed deer, that have been observed utilizing a preexisting unintended WCS have increased their usage after the new WCS was installed

(McCollister and van Manen 2010). Location G is a designated to be replaced with a WCS when the project reaches the area. By replacing the existing culvert already being used by wildlife with a WCS, usage may increase as shown by McCollister and van Manen 2010. This study further bolsters our decision for the location and placement of WCS within the study area. We can also link this to immediate utilization of the currently installed WCS by meso-mammals such as raccoons. These structures were previously documented as being used by wildlife before they were replaced with the current WCS and as a result currently being utilized by these species. This shows the importance of a preemptive study to gain an understanding of areas where wildlife is present when planning to install a WCS along a roadway system.

With the disturbances ceasing around the installed WCS and as animals become acclimated to these structures I believe we will see an increase in usage by wildlife. Acclimation times can vary by species, as mentioned previously. Elk (*Cervus elaphus*) respond relativity quickly to the installation of WCS, while other species require up to five years to acclimate (Clevenger and Waltho 2003). However, different studies show that acclimation time for elk utilizing WCS is longer (Dodd et al. 2007). This shows that the acclimation times can vary within the same species, possibly dependent on the location. The presence of animals utilizing an already installed large box culvert (installed for 5+ years) for movement may show that wildlife within our study area may already be acclimated to WCS, further reducing the acclimation time and resulting in animals utilizing the WCS sooner. Although acclimation time can be variable we already have seen wildlife utilize the recently installed WCS both during and post-installation.

Continued construction and disturbance of the WCS may well have resulted in a delay of use of structures by wildlife and the lack of observations from our camera traps. As of 19 September 2016, the heavy construction of the first two WCS and the area undergoing road expansion have been completed, including final revegetation. In-stream erosion control structures were also completed in December of 2016, along with final cessation of construction disturbances. These disturbances might be the cause of animals evacuating the area and not utilizing the WCS even after they have been completed. Disturbances such as the construction of roadway systems have been shown to alter species compositions and movement patterns within habitats (Wilcox and Murphy 1985; Reed et al. 1996; Forman and Alexander 1998; Coffin 2007; Lopez et al. 2010; Ree et al. 2011). I found that from December 2016 to May 2017, after construction was completed, there was an increase in observations of feral hogs at the Goodwater WCS structure. This might indicate that animals are returning to the habitats surrounding the highway system. By continuing to monitor these WCS post-construction we can determine not only the species that utilize them, but also how long these species take to acclimate to the installation of structures, as well as any changes in wildlife mortality along the roadway. Monitoring of this section of roadway post-construction is imperative in determining the outcomes from the actual construction disturbance as well as examining the usefulness of the installed WCS.

Our overall monitoring efforts seek to increase our understanding of the mitigation efforts (i.e. installation of WCS) and their impacts on not only the Houston Toad, but also, general wildlife in the area, as well as reducing negative wildlife motorist interactions. Long term monitoring is imperative to understand and observe wildlife acclimation time and usage of these WCS (Clevenger and Waltho 2003; Gagnon et al.

2011). Combining the observations of animals utilizing the WCS and the observations of wildlife mortalities found in the next chapter, we will be able to determine the overall impact of these WCS as animals begin to acclimate to these structures and use utilize them to traverse the highway system.

CHAPTER 3
EXAMINING AREAS OF ROADWAY USED BY WILDLIFE BASED ON ROADKILL USING VARIOUS SURVEY METHODS.

INTRODUCTION

Monitoring roadkill is an integral part of understanding which areas along a roadway system have the greatest usage by wildlife. Knowing which areas have the highest mortalities allows for transportation planners to implement the best management strategy along roadway systems. Occurrences of roadkill along roadways can be significant, and has been shown to impact common, threatened, or endangered species (Dickerson 1939; Aresco 2006; Hobday and Minstrell 2008; Laurence et al., 2009). Not only do WVCs impact species populations, they also have a direct impact on human life and property. Wildlife-vehicle collisions can result in damage to vehicles, the roadway, and in some cases result in the loss of human life (Seiler 2005). Because public safety is a top priority to both transportation departments and transportation planners, management techniques that reduce WVCs are vital to benefit both human and wildlife welfare. By understanding which areas have the highest density of roadkill we are better able to understand and implement mitigation efforts to solve this issue.

Efforts to monitor roadkill involve conducting driving surveys along a roadway system and documenting the occurrence of roadkill (Taylor and Goldingay 2004; Hobday and Minstrell 2008; Beckmann and Shine 2015). However, the methods utilized to collect these data can be highly variable and lack resolution, particularly if there is a target species in mind. Some methods conduct roadkill surveys by driving the roadway and documenting the approximate location of the animal and the species without stopping to verify the correct species and location (Hobday and Minstrell 2008). This creates a lack of resolution in the data collected, especially if smaller species such as reptiles or amphibians are the focus of the study. Another type of surveyor bias is included if the observed roadkill is, or isn't, physically marked on the roadway system. The removal, or marking, of the animal by flagging, painting, or other visual representations, allows the user to see that the animal has been previously observed which removes the possibility of double counts (Aresco 2006; Hobday and Minstrell 2008). Removal of roadkill was also shown to vary between studies (McCollister and van Manen 2010). The results varied by roadkill either being removed from the roadway to reduce double counting (Aresco 2006; Hobday and Minstrell 2008), or being left on the roadway (McCollister and van Manen 2010). Roadkill occurring in a shoulder also presents another issue. While some systems have established shoulders, others do not, and the maintenance of vegetation on the sides of the roadway is highly variable. This creates an issue when counting roadkill occurrences because potential observations can be hidden within the vegetation or on the shoulder and out of view of the observer. Implementing walking transects along subsets of the roadway can allow for an increase in detection of roadkill observations further bolstering the data set (Langen et al., 2007). Obviously a walking method also enables smaller animal detections than can be done in a driving survey alone, simply by the size of a small amphibian vs. that of a mesocarnivore mammal like a skunk. Creating a survey method that is both time efficient, and collects the data to the highest resolution needed, is an important aspect of any road ecology study aiming to determine which areas along a roadway are being utilized more frequently, and the types of species utilizing them.

Traditional roadkill surveys can be the optimal method for collecting the most data needed for a monitoring project. However, depending on the traffic volume of the roadway system it may not always be the safest. As stated, part of traditional surveys is documenting species and location of the observation, as well as marking the observation. This presents a potential risk for the researcher by forcing them along high traffic, and potentially high speed, roadways. Safety is a continuous concern for both the researchers as well as the transportation agencies who may be working in conjunction with the researchers. Thus, developing a roadkill survey method that can increase the safety of the researcher can prove even more valuable than one with bias. Advancements in technology has led to the availability of video recording devices that have continued to decrease in size yet increase in resolution and frame rate options. Creating a system that would allow for the implementation of these recording devices, such as GoPro cameras, could allow for a researcher to collected the needed data without ever having to leave the safety of their vehicle.

Here we aim to examine the effectiveness of existing and proposed WCS installed at a total of four locations (Fig. 20 and 21) along a roadway system in the Lost Pines ecological area. Construction of two of these crossings was completed in 2016. Three survey methods were implemented to determine the effectiveness of the installed WCS: 1) Video driving surveys, 2) Driving surveys, 3) Transect surveys. The primary focus of this study is to determine the sections along the U.S. Highway 290 study area where roadkill occurs. These data combined with the WCS monitoring data will be used to determine if there is a reduction in roadkill in the areas where the WCSs were installed, as well as areas that would benefit from future installation of WCS. Observations of roadkill were compared to determine the variation in detection of wildlife mortalities between the three survey methods used in the study. Finally, we aimed to develop a safer method of wildlife mortality surveys by utilizing GoPro video cameras to collect roadkill observations. This method, if proven successful, aimed to create a methodology that would allow researchers to collect the data required for their study while reducing risks associated with traditional wildlife mortality surveys.

MATERIALS AND METHODS

Study site.— See Chapter 1 for study site description. Data collection and monitoring efforts began January 2016 and will continue until May 2017.

Survey design.— Wildlife mortality surveys were conducted within the study site using three different survey methods: driving the roadway (visual survey), driving with video recording devices, and walking sections of the roadway. These three survey methods will be used to locate roadway sections of the study area with highest wildlife mortality density. Variation in detectability of recorded observations were also compared between the three survey methods. Each survey method was conducted bi-weekly on the same day in the following order: driving with video, driving the roadway, and walking sections of the roadway. Conducting the video survey first attempted to reduce bias in survey method as a result of seeing observations on the roadway for the first time.

Video survey. —Wildlife mortality surveys were conducted along the roadway found within the study site using modern video recording equipment. This method was used in an attempt to develop safer survey protocols for high usage highway systems allowing the user to only have to exit their vehicle to mount and dismount the camera systems. Two GoPro Hero 3+ Black cameras were used to attach to the vehicle that will be used while conducting the surveys. Both cameras were set at a resolution of 1080p and recorded at 60 frames per second. A mount was fabricated to allow cameras to be placed closed to the roadway. This mount was comprised of a 1.8-meter-long two-by-four with two camera mounts placed 0.3 meters from each end. The mount is then connected to the frame inside the bumper of the vehicle resulting in the cameras being 0.5 meters off of the ground (Fig. 18). The cameras and mounting system were mounted upon arrival at the study site. Due to the roadway being a four lane highway, the section of U.S. Highway 290 was driven twice (Outer lane and Inner lane) to increase potential captures of road kill. Vehicle speed was set to 80.5 kilometers per hour (kph) and video survey was conducted on each section of roadway. Video data collected was analyzed and captures were denoted to the most specific taxon possible.

Driving survey. —Driving surveys were also conducted bi-weekly along the section of U.S. Highway 290. Driving speeds were the same as the video surveys, 80.5 kph, and the roadway was surveyed in an attempt to locate dead on the road (DOR) animals. Upon locating DOR's, data was collected at each location and the DOR was marked with high visibility marking paint to prevent double counts. Data collected include: species type, date, GPS location, transect number, which side of the roadway, and if its in the roadway or in the shoulder area. All animal carcasses were not removed from the roadway.

I also examined wildlife mortality rates within the study area for both treatments. These were calculated based on previously studies by calculating wildlife mortalities per kilometer of roadway per day (Ashley and Robinson 1996). To calculate mortality rates observations from driving surveys and walking surveys were combined and examined for two time periods, during construction and post construction/installation.

Walking Survey. —Transect surveys were conducted in each of the treatments (NCT and CT) along the roadway system. The data collected using this survey method was used to determine differences in detection probabilities between walking and driving surveys as a result of potential DOR's being out of site along the shoulder areas. Each treatment is comprised of 402.3 meter long transects. Buffer zones were placed at the end of each treatment as well as in between both treatments to reduce edge effect. NCT resulted in a total of 16 transects and CT resulted in 11 transects (Fig. 19). Four transects were randomly drawn from each treatment type and surveyed bi-weekly. Areas along the roadway within each transect were walked, and searched, in an attempt to find DOR's. Data collected included: species type, date, GPS location, transect number, which side of the roadway, and if the observation was in roadway or in the shoulder area. DOR's were marked with high visibility marking paint to prevent double counts throughout the study. Data collected from this survey method was used to compare differences in detections between the standard driving survey.

Analyses— In order to compare differences in count observations of DOR's between the two treatments, Construction and No Construction, a Generalized Linear Mixed Effect Model (GLMM) was utilized. By comparing the observations in these two treatments I was able to make an assessment on the status of DOR observations over time as a result of the installed corridors in the Construction treatment. I also compared the observations of DOR's among treatments to determine if the construction disturbance influenced DOR observations. A GLMM was also used to evaluate the observations recorded between two survey types, driving and walking. With this analysis I used observations as the response variables, treatment and treatment survey type as the fixed effects with transect as the random effect. A negative binomial or Poisson distribution was used to fit the data as a result of it being non-normal. The appropriate model was chosen based on the resulting AIC score. As a result, I was able to determine which method provides the highest resolution in regards to mortality surveys along a roadway system. These analyses were conducted in RStudio using the package glmmADMB (Skaug et al., 2010).

RESULTS

Driving survey—Results from January 2016 to May 2017 resulted in a total of 243 wildlife mortality observations from 31 surveys. A total of 30 different species were observed and identified to the lowest taxonomic level (Fig. 22). Remaining observations were identified as; Aves, Mammalia, Serpentes, Anuran, or Unidentified (UNID). Red-eared slider (*Trachemys scripta elegans*) had the highest number of mortality observations (n = 33) followed by opossum (*Didelphis virginiana*) (n = 31) and skunk (*Mephitis mephitis*) (n = 18). No DOR Houston Toads were observed. There were a higher number of observations in the NC treatment (n = 125) (Fig. 23) compared to the Construction treatment (n = 118) (Fig. 24). These data were fit to a negative binomial 1 distribution (AIC = 173.7) and I found that observations in the NC treatment were not significantly different than the C treatment (P = 0.41). Due to the post construction/installation period being shorter I also compared during construction observations from January 2016 – May 2016 to post construction observations from January 2017 – May 2017 and found no significant difference between treatments (P =

0.41, negative binomial 1 model fit).

Mortality observations during the walking and driving surveys were combine to determine mortalities per kilometer per day (DOR/km/day). I found the construction treatment during the in construction period resulted in 0.04 DOR/km/day. This mortality rate increased during the post construction period to 0.09 DOR/km/day. Mortality rates within the No Construction treatment resulted in 0.04/DOR/km/day.

Walking survey—Analysis comparing observations made while walking compared to driving the roadway found 121 DOR observations while walking compared to 40 DOR observations while driving. These data were collected from January 2016 to May 2017. I found that the method of walking surveys was significantly different when compared to driving surveys (P = 5.0e-07). These data were fit to a negative binomial 2 (AIC = 696.5) distribution using a GLMM.

Video survey—A total of 12 video surveys were conducted in conjunction with the two other survey methods; walking transects and driving. When comparing the 12 video surveys to the corresponding driving surveys a total of 33 observations were found using the video survey method while 57 were found using the driving method. There was shown to be a significant difference (P = 0.012) between the survey methods showing the video survey produces less observations. Of the 33 observations found utilizing the video survey method 27 of them were unable to be identified while 6 of them were identified to the species level. Whereas the driving surveys yielded only 5 mortality observations that were unable to be identified out of 57 observed.

Discussion

With the current data that has been collected there is no significant difference between the areas that are undergoing the construction disturbance compared to the areas where no construction is occurring. Disturbances such as the construction of roadway systems have been shown to alter species compositions and movement patterns (Wilcox and Murphy 1985; Reed et al., 1996; Forman and Alexander 1998; Coffin 2007; Lopez et al., 2010; Ree et al., 2011). However, the roadway in this study is already established and is only being widened. Although the disturbance of the construction due to the highway expansion may drive animals out of the area, the high usage of this established highway system can potentially act as a deterrent to animal attraction and movement. As a result, we may not see any significant difference between treatments. Out of the 243 DOR observations 69 of them were species of herpetofauna. These species were observed in both the NC and C treatments with no differences in abundance of observations. The remaining observations included small mammals (raccoons, opossum, armadillo), mesocarnivores and large mammals (coyote, bobcat, white-tailed deer, feral hog) and species of aves (screech owl, great-horned owl, turkey vulture). While no Houston Toad DORs were observed during this study, the raw numbers of species DOR along the highway show the impact of the roadway system on wildlife.

Though this roadway system may negatively impact wildlife in the area these negative impacts extend to humans with an increased probability of wildlife-vehicle collisions. The installation of WCS aims to reduce these negative impacts not only for wildlife, but for human interactions as well. By continuing to monitor wildlife mortalities along this highway system as we move away from project completion date we can better evaluate the impacts that these WCS have on wildlife mortality in the study area. Dodd et al. (2004) monitored a section of roadway for a year after culvert and barrier walls were installed in an effort to reduce wildlife mortalities in the Paynes Prairie State Preserve. They were able to show that the structures decreased the wildlife mortalities in the study area post construction. Initially they found 2411 DOR observations in the year leading up to the construction of the structure. Post construction they observed 158 DOR observations showing that the structure drastically increased the wildlife mortalities within the study area (Dodd et al., 2004). In the case of our study, completion of the WCS occurred recently (December 2016), by monitoring the roadway as shown in Dodd et al., 2003, we can better understand the implications of the installed WCS and their impacts on wildlife mortalities. As stated in the previous chapter, multiple studies (Ashley and Robinson 1996; Dodd et al, 2004; Aresco 2005; McCollister and van Manen 2010) show that wildlife mortalities decrease within the study area as a result of the WCS being implemented. Aresco (2005) saw a decrease in DOR/km/day from 11.9 to 0.09 over 2.5 years. This drastic decrease in mortalities observations is as a result of WCS and funnel barriers were installed along a roadway that bisect wetlands. Currently I have documented wildlife mortality rates that were shown to be relatively low compared to previous studies (0.04 during construction and 0.09 post construction). However, I did observe an increase in mortality rates post installation of these WCS. This could be a result of the removal of siltation fencing which created a barrier excluding animal movement into the work site and roadway. This may also be a result of the increased road surface area of the completed portion of roadway. As mentioned previously this roadway was converted from a four lane undivided highway to a four lane divided highway greatly increasing roadway surface area as well as increasing the distance for an animal to traverse. These data, post construction specifically, provide the baseline mortality rates that can be examined as the roadway system is monitored overtime. By continuing these mortality surveys we can determine if we achieve results such as previous studies by reducing wildlife mortalities as a result of the WCS implementation.

Although there is no difference in observations between treatments we also see that the locations of the WCS currently exhibit higher densities of wildlife mortalities (Fig. 24). Disturbances at these locations were more frequent as a result of the bridge and culvert installation and the main focus of the project area. By continuing the current monitoring strategies, we seek to determine if differences in wildlife mortalities along the roadway are present, and then, if those differences are correspondent to a lower incidence near the WCS installations. This provides a baseline dataset to a monitoring project that will need to continue and act as a longevity study in order to fully determine the status of usage of WCS and resulting impacts on wildlife mortalities (Clevenger and Waltho 2003; Gagnon et al., 2011). This is also important as road expansion progresses west and moves further into the current area designated as the NC treatment. The methods implemented here and the baseline data collected in the NC treatment will allow for the comparison of animal DORs to determine the impact in this area as well. As we move into the post-construction phase of this project and animals begin to acclimate to these structures we expect to see a decrease in wildlife mortalities at or around the locations of these WCS. Efforts to reduce the DORs and increase usage of the WCS could extend to installing funnel fencing around the WCS locations aiming to increase wildlife's awareness of the WCS by directing them to the structures.

By creating a robust survey method such as walking transects as well as driving surveys, I was able to increase the resolution and, thus, accuracy of our observations within the study area. I was able to determine that walking transects do, in fact, increase our detections of wildlife mortalities. These results reflect similar results showing detectability of herpetofauna was significantly lower than by walking transects along the same portion of highway (Langen et al, 2007). Overall, driving surveys were shown to underestimate the wildlife mortality densities along a rural New York highway as a result of the reduced ability to detect animals during driving surveys. Gerow et al. 2010 showed that observers who walked the portion of roadway generated 1,286 vibrate observations compared to 83 observations detected by drivers (Gerow et al., 2010). These previous studies combined with ours show that utilizing a mixed survey method or simply walking the entire study area generates more observations resulting in a more accurate wildlife mortality density along a roadway. These efforts increase our resolution of DOR's along the roadway resulting in higher quality data that can better guide the decision-making process in regard to locations for future installation of wildlife crossing structures. However, depending on the area of highway that is being monitored, surveying the study site by walking may not be a feasible option. Utilizing an all-terrain vehicle could allow the surveyor to more efficiently survey the area while still allow for the increased resolution of observations. Overall, implementing both walking and driving surveys increased the resolution and number of observations of wildlife mortalities within the study area.

Utilizing video recording devices to monitor the study area for wildlife mortalities proved to be variable. Currently the technology does not meet the utility of cameras to identify DOR observations. These cameras allowed for the determination of an observation to be determined to be a mortality event but the ability to successfully identify the observation to the species level did not prove to be successful. This is due to a resolution and framerate per second (fps) tradeoff. The highest resolution these cameras provided was 4K resolution. Using this setting allows for a high resolution image but sacrifices framerate per second (10 fps). This creates an issue as a result of not enough images captured in the video causing instances of have a before or after of the DOR or the DOR not being documented all together. I sacrificed resolution for a higher fps in order to capture DORs on the roadway. This caused images to be lower resolution (1080p) and reduced the ability to identify the species of the DOR. Issues also arouse in the No Construction treatment where the shoulder was absent. Unlike the Construction treatment that has a paved shoulder the NC does not. This hinders the ability to of the cameras to efficiently capture DORs due to the vegetation height. Certain species are easily identified based on their distinct morphology. Skunks, for example, were easily determined in the survey video due to their morphology (Fig. 25). However, animal carcasses on the roadway were often unable to be identified due to vehicles driving over them, scavenger predation, and general decay of the carcass (Fig. 26). Traditional survey methods allow you to exit the vehicle and examine the carcass allowing for the researcher to better identify the observation. That was not the case in this method as a result of attempting to develop a safer method of mortality surveys.

Although there were issues with successfully identifying DORs this method utilizing cameras could still prove to be beneficial depending on the desired resolution of the wildlife mortality event. If the species of the DOR observation is irrelevant then this method of surveying for wildlife mortalities along a highway system could be implemented. This would provide the location and abundance of DORs along a highway system as well as create a safer method of surveying for the researcher. In our case we this project was based around the endangered Houston Toad. The ability to identify an observation to the highest taxonomic level is vital in providing a better understanding of a disturbance on a species of concern. However, as technology increases this method of surveying for wildlife mortalities along a high trafficked roadway system will become more viable. Currently cameras are becoming more affordable and resolution/fps is increasing. A tech company called YI recently released an action camera with the ability to record at 4K resolution and 60 fps. The cost of these cameras has also decreased to 199$ USD, as compared to 349 $ USD for the GoPro Hero 3+ Black utilized in this study. Implementing these cameras may generate optimal image results to allow for identification at the lowest taxonomic level of a wildlife mortality.

At this time, it is too early to make an assessment on the implications the WCS have on wildlife mortalities within the study area. As shown in previous studies, including ours, small mammals utilize the WCS almost immediately post-construction (Valladares Padua et al., 1995, Mansergh and Scotts 1989). The increase disturbance due to the roadway construction did not generate any difference in wildlife mortalities. Although the WCS were only recently competed (December 2016) we do see small mammals beginning to utilize these structures to traverse the highway. However, we do not see a reduction in mortalities at these locations or in the construction treatment in general. Currently, the WCS do not have any form of funnel fencing or barrier diverting animals into the WCS. The absence of this fencing is not shown currently to play any impact on animals utilizing WCS. However, previous studies show that WCS being implemented not in conjunction with fencing do no reduce wildlife mortalities along the roadway (Rytwinski et al., 2016). It is imperative to examine the effectiveness of our installed WCS without fencing and their resulting impact on DORs along the roadway and WCS usage by animals. By continuing these monitoring efforts we aim examine these potential issue and hope to see a reduction in wildlife mortalities around these WCS as wildlife begins to acclimate to these structures. By creating the robust mortality survey methods and combining them with the camera trap monitoring of the WCS themselves we will be able to increase our ability to make an assessment on the implications of these WCS over time.

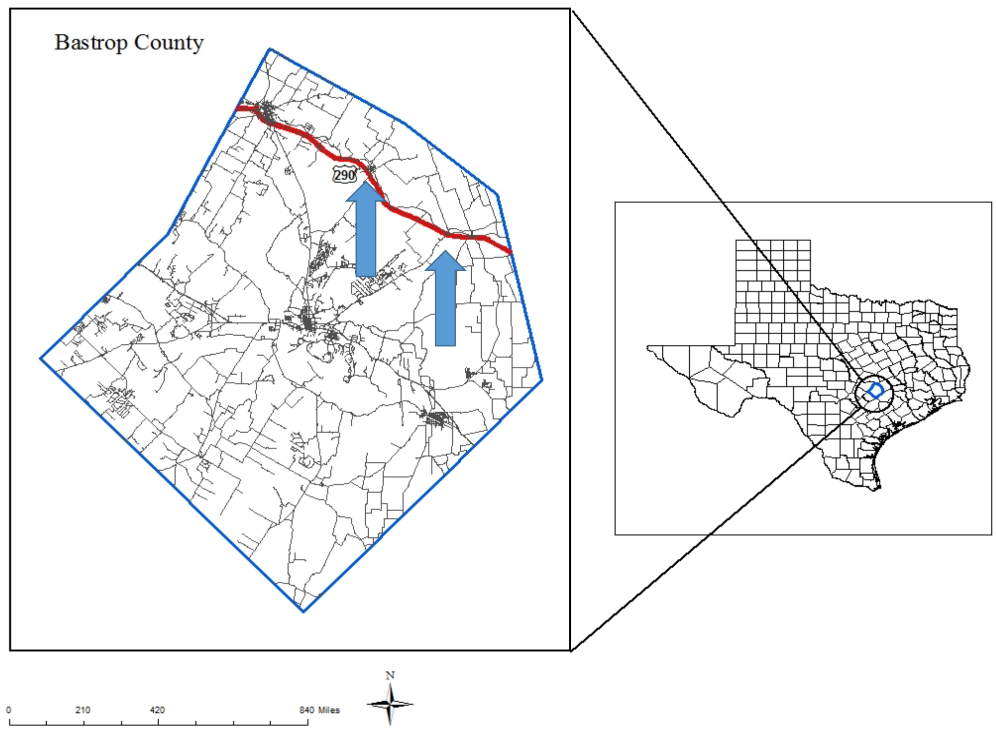

Figure 1. Map of Bastrop County, Texas with the U.S. Highway 290 study area highlighted in red for reference. The blue outline represents Bastrop County, which is found in the Lost Pines ecoregion of central Texas. Colored arrows represent the end boundaries of the study area on U.S. Highway 290.

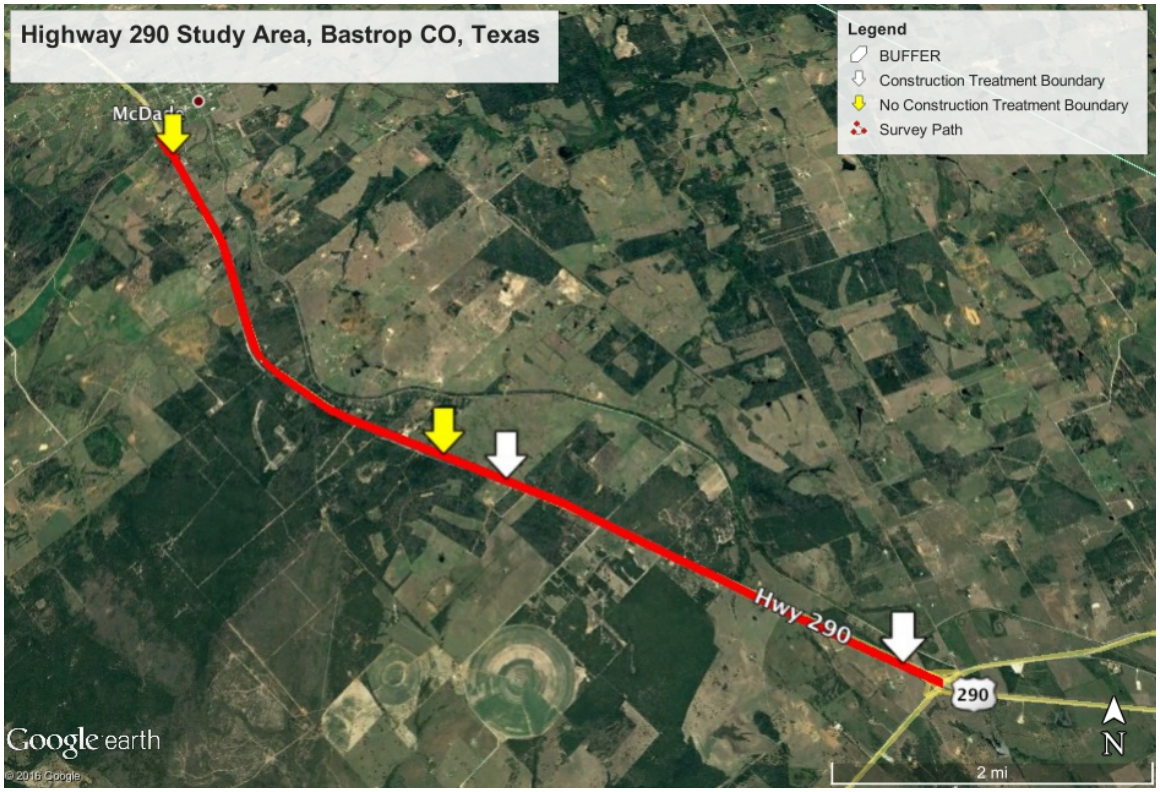

Figure 2. Aerial view of the study site displaying the 12.5 km stretch of Highway 290 bordered to the east by Highway 21 and to the west by FM 2336. This portion of highway is located north-east of the city of Bastrop, Texas. Colored arrows represent beginning and end segments of each treatment, Construction (white arrows) and No Construction (yellow arrows).

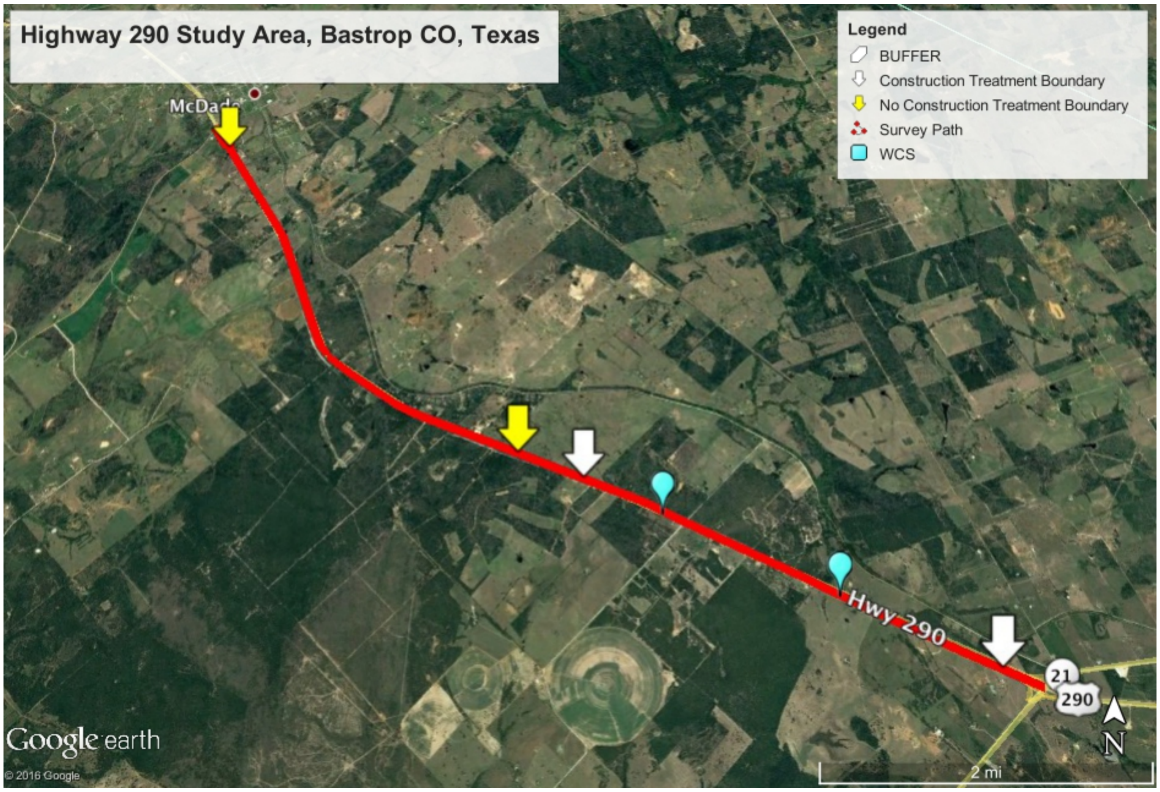

Figure 3. Aerial view of the study site displaying the 12.5 km stretch of U.S. Highway 290 bordered to the east by Highway 21 and to the west by FM 2336. This portion of highway is located north-east of the city of Bastrop, Texas. The placement locations of the two wildlife underpass corridors are displayed above and denoted as Goodwater and Midsprings. Colored arrows represent beginning and end segments of each treatment, Construction (white arrows) and No Construction (yellow arrows).

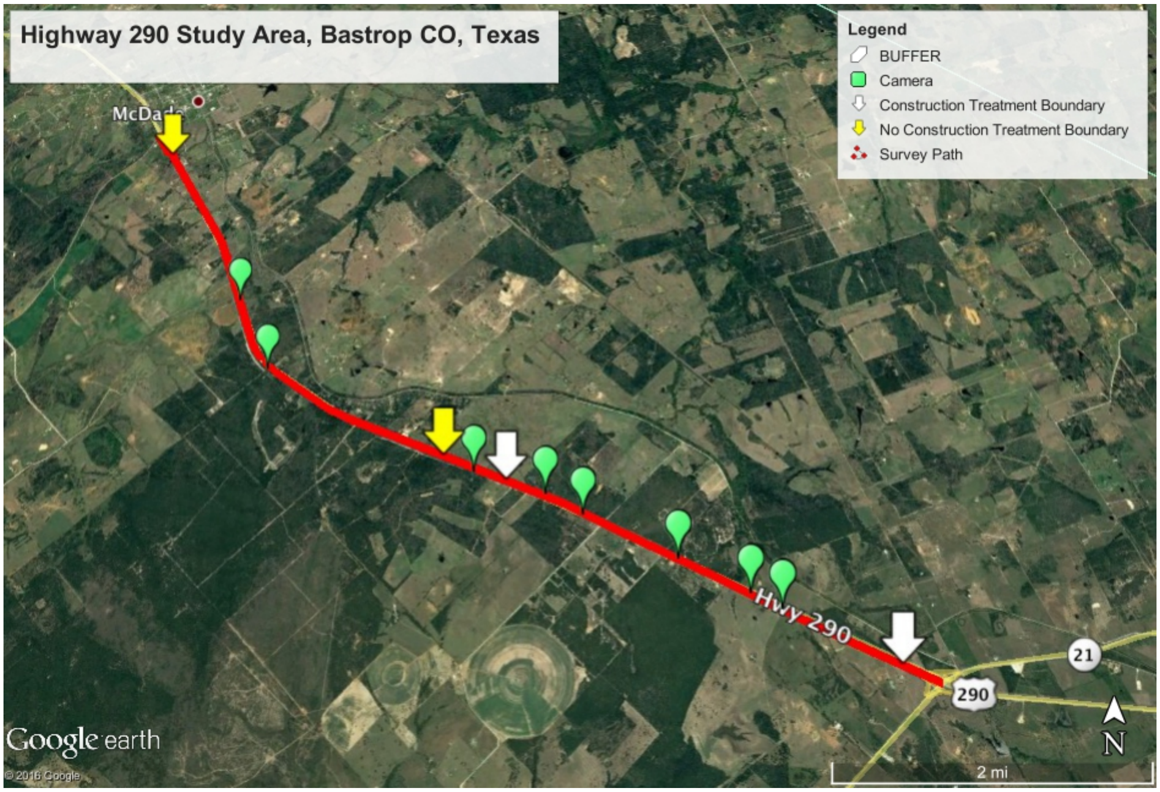

Figure 4. Locations of each camera denoted by the green markers. Cameras were placed at a pre-existing culvert as well as the two new wildlife underpass culverts. Colored arrows represent beginning and end segments of each treatment, Construction and No Construction.

Figure 5. Track pads installed at the north and south ends of each of the wildlife underpass corridor displayed above. The track pads span the width of the corridor and are 2.5 meters long. Track pads are checked bi-weekly and raked to prevent double counts when checked in future surveys.

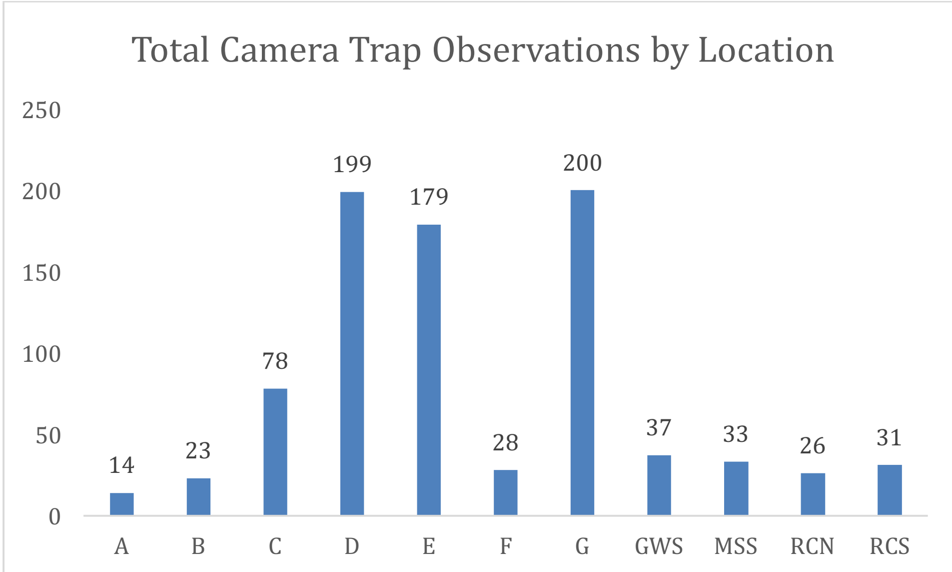

Figure 6. Camera trapping results by location from January 2016 to May 2017 within the 12.8 km section of US Highway 290 in Bastrop County, Texas. Total observations are displayed by camera trap location. Out of the eleven camera trap locations three resulted in the highest observations; G (n=200), D (n=199), and E (n=179).

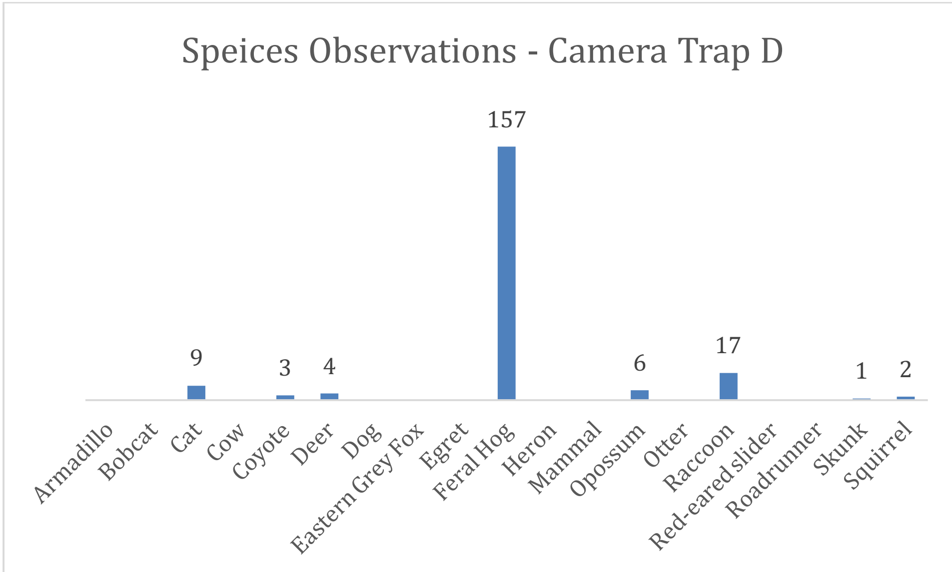

Figure 7. Camera trapping results from January 2016 to May 2017 within the 12.8 km section of US Highway 290 in Bastrop County, Texas at camera location D. Camera trap D had the second highest number of observations out of the eleven cameras in the study area. Observations consisted primarily of feral hogs, but also included raccoon, domestic cat, coyote, deer, opossum, skunk, and squirrel. This location is at the northern entrance to the Goodwater WCS.

Figure 8. Goodwater South camera trap observation showing a domestic dogs exiting the WCS. This location is the western most WCS in the Highway 290 Study area in Bastrop County, Texas. Domestic dogs tracks were also observed at the trackpad located at this WCS.

Figure 9. Track pad observations found at the Goodwater North track pad. Species observed include raccoon and feral hog. Track pads were monitored for presence absence of animals at each location. Raccoons were found to traverse the WCS but feral hogs were only shown entering the north entrance but not crossing.

Figure 10. Track pad observations found at the Goodwater North track pad. Species observed include raccoon and feral hog. Track pads were monitored for presence absence of animals at each location. Raccoons were found to traverse the WCS but feral hogs were only shown entering the north entrance but not crossing.

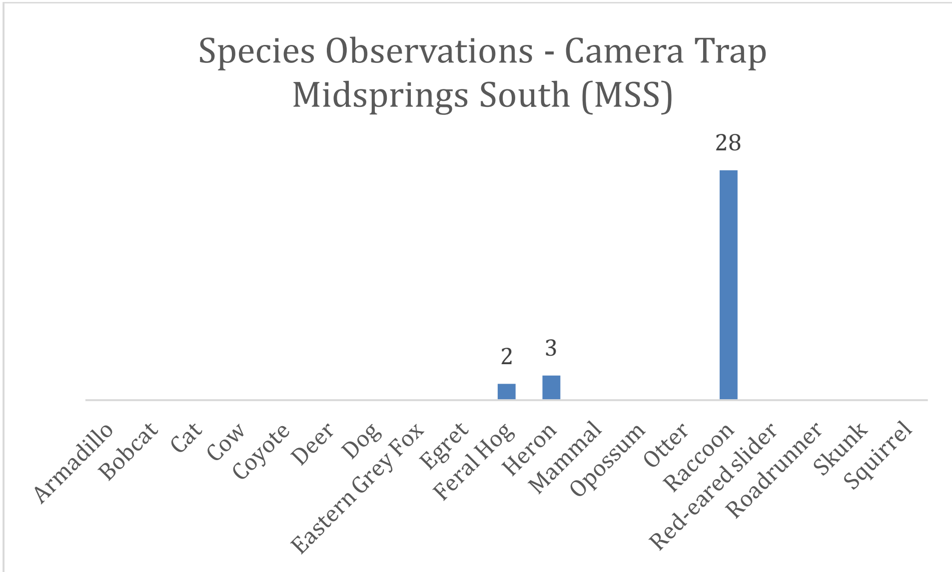

Figure 11. Camera trapping results from January 2016 to May 2017 within the 12.8 km section of US Highway 290 in Bastrop County, Texas at camera location MSS (Midsprings South). MSS is located at the southern entrance to the Midsprings WCS. A total of 33 animals were captured at this location. Observations consisted primarily of raccoon, but also included feral hog and heron.

Figure 12. Midsprings South camera trap observation showing a raccoon entering the WCS. This location is the eastern most WCS in the Highway 290 Study area in Bastrop County, Texas.

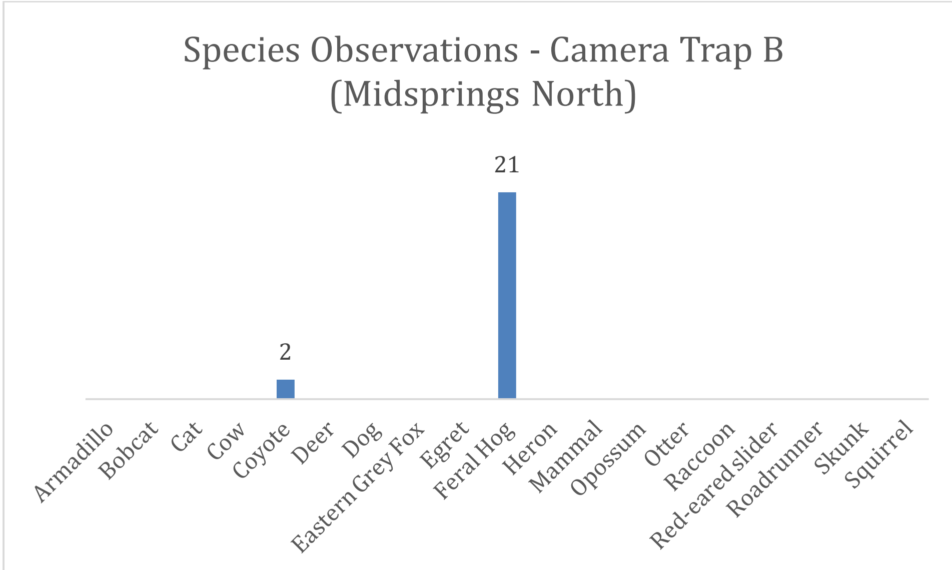

Figure 13. Camera trapping results from January 2016 to May 2017 within the 12.8 km section of US Highway 290 in Bastrop County, Texas at camera trap location B. This camera trap is located at the northern entrance to the Midsprings WCS. A total of 23 animals were observed and consisted primarily of feral hogs. The remaining observations were coyotes.

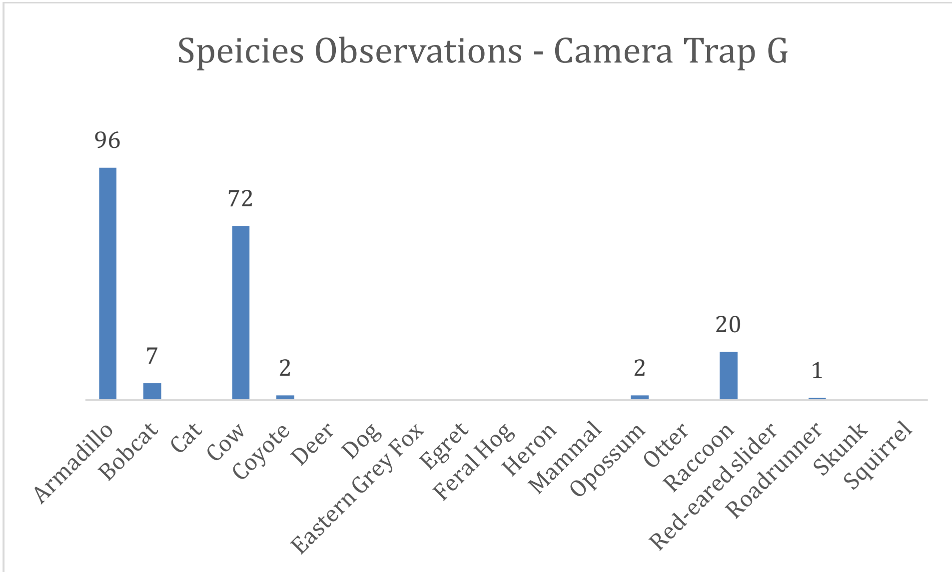

Figure 14. Camera trapping results from January 2016 to May 2017 within the 12.8 km section of US Highway 290 in Bastrop County, Texas at camera location G. Camera trap G had the highest number of observations out of the eleven cameras in the study area. Armadillo and domestic cow were the highest number of observations. Remaining species observed include; bobcat, coyote, opossum, raccoon, and greater roadrunner.

Figure 15. Camera trap G observation capturing a bobcat (*Lynx rufus*) entering a preexisting large box culvert. This culvert location is in the No Construction treatment of the Highway 290 study area in Bastrop County, Texas. This culvert is an already established large box culvert which animals have become acclimated to and currently use to traverse the roadway.

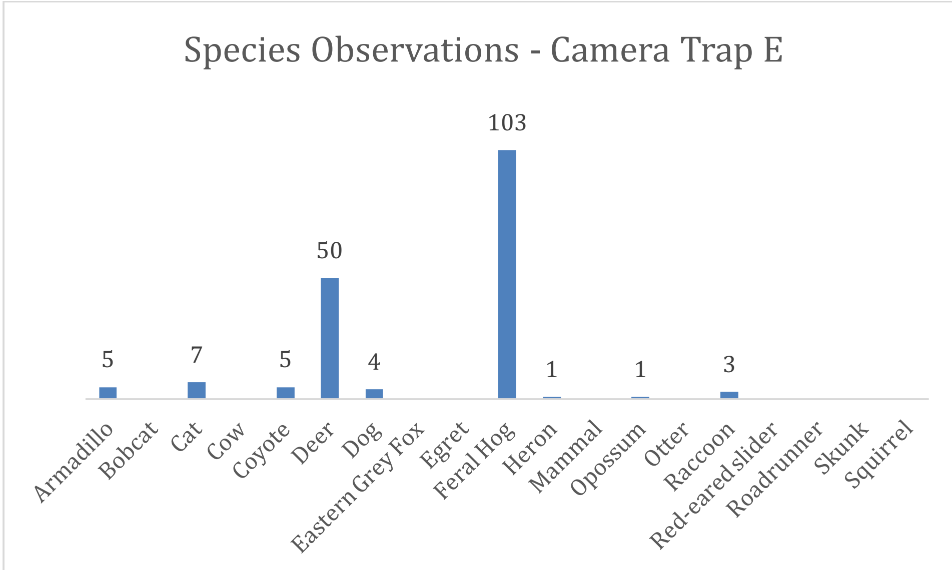

Figure 16. Camera trapping results from January 2016 to May 2017 within the 12.8 km section of US Highway 290 in Bastrop County, Texas at camera location E. Camera trap E had the third highest number of observations out of the eleven cameras in the study area. Feral hog had the highest number of observations followed by white-tailed deer. Remaining species observed include; armadillo, domestic cat, coyote, domestic dog, heron, opossum, and raccoon.

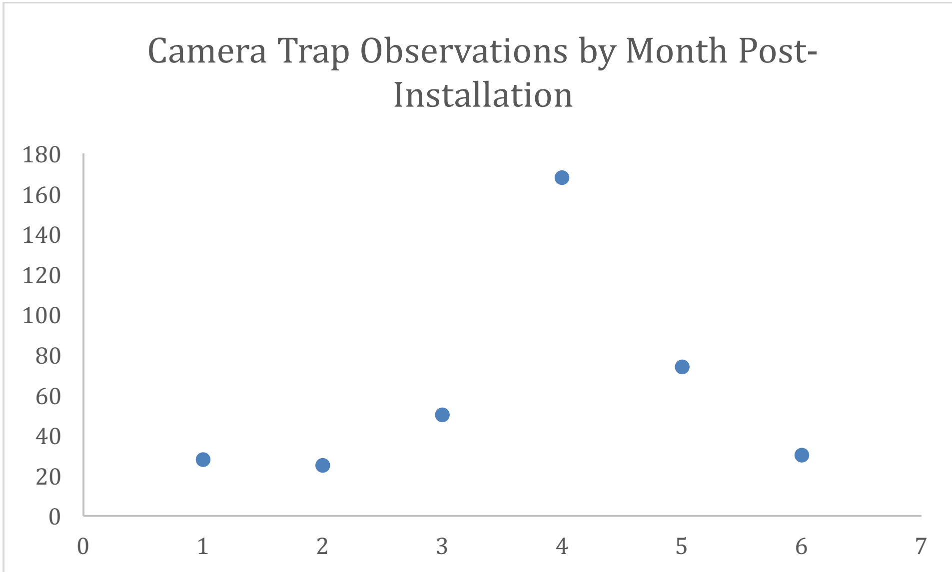

Figure 17. Camera trap observations from locations within the Construction treatment in the five months' post construction. The month of march (denoted 4) saw an increase in captures (n = 168) compared to February and April. Increase in observations is attributed to the increase in presence of Feral hogs within the study site and captured on the camera traps.

Figure 18. Photographic display of the mounting device created to conduct video roadkill surveys for this study. The mount is comprised of two-by-fours, mounted to the frame of the vehicle, with a GoPro Hero 3+ Black camera mounted on either end. This mounting device allows for the cameras to be placed close to the roadway in attempts to identify roadkill.

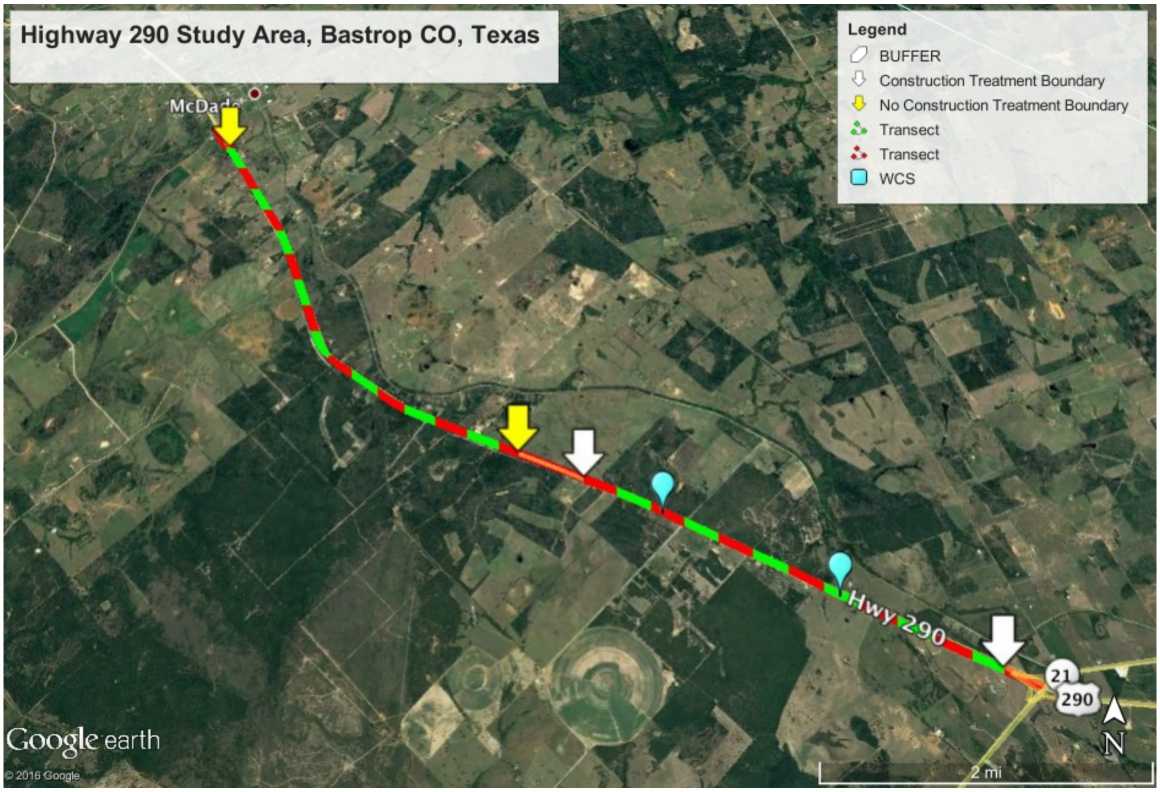

Figure 19. Map displaying the designated transects for the walking surveys along in the study area. Alternating red and green lines represent different transects. Buffer zones are displayed in between the two treatments and at the end of each treatment by pink zones. Colored arrows represent beginning and end segments of each treatment, Construction and No Construction.

Figure 20. Wildlife underpass corridor currently installed at the south Goodwater location in the U.S. Highway 290 study site in Bastrop County, Texas. As shown above, the WCS is comprised of a culvert drainage system and bridges to allow for wildlife to traverse the highway.

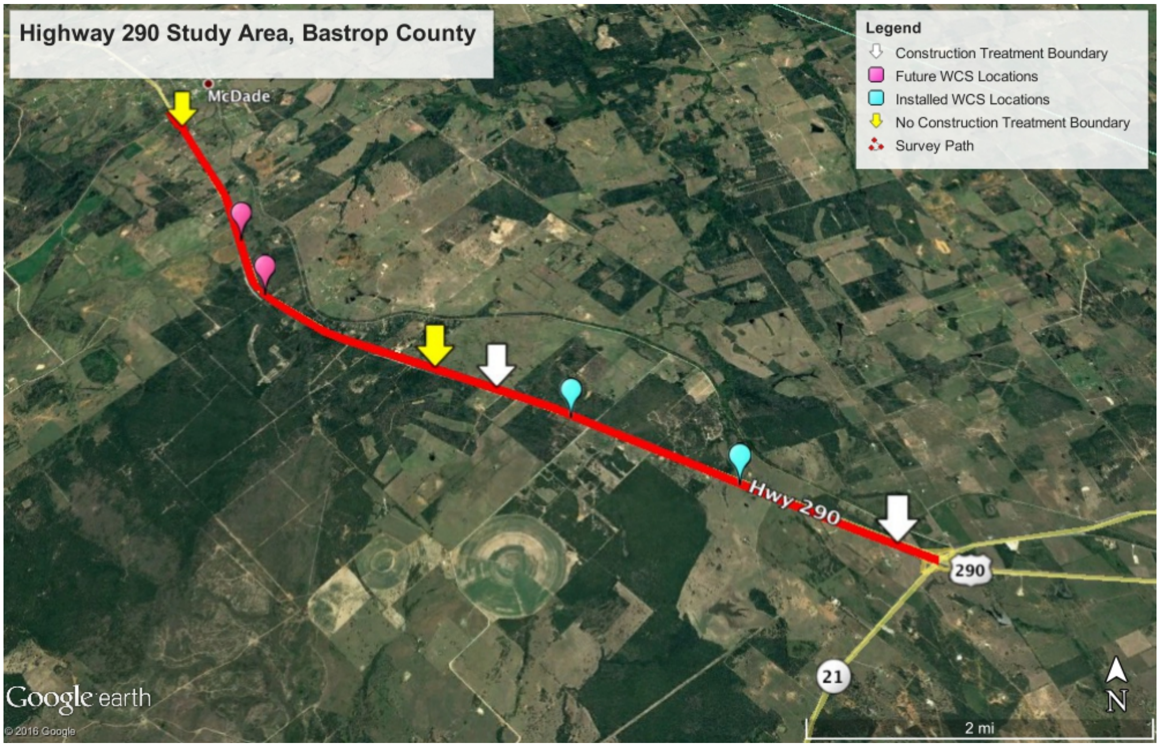

Figure 21. Overview of US Highway 290 study area. Locations of WCS that are currently installed are displayed as well as the locations of the planned, to be installed, WCS. Current WCS were completed September 2016.

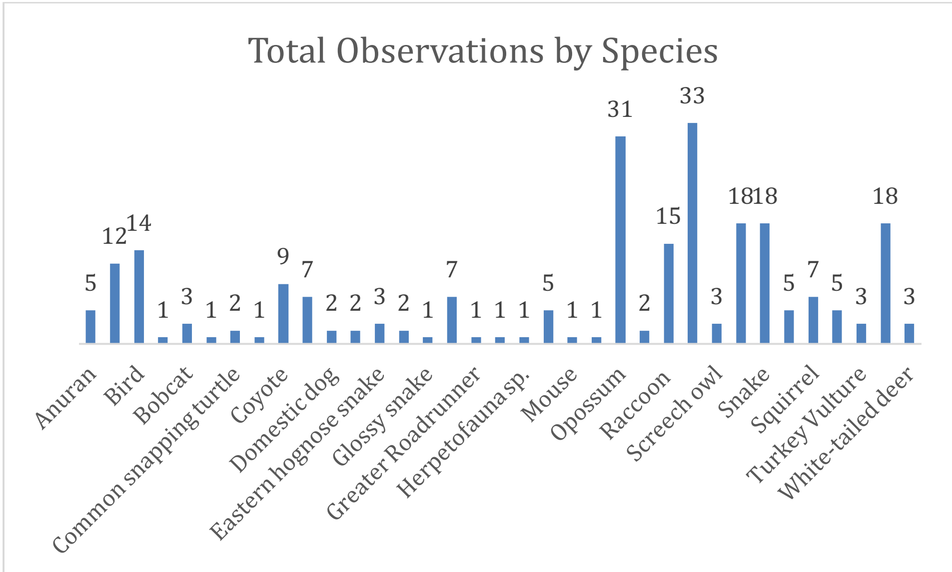

Figure 22. Total wildlife mortalities observed within the 12.8 km section of US Highway 290. Species observations were collected from January 2016-May 2017. Species observed with the highest number of mortalities were red-eared slider (*Trachemys scripta elegans*) followed by opossum (*Didelphis virginiana*) and skunk (*Mephitis mephitis*).

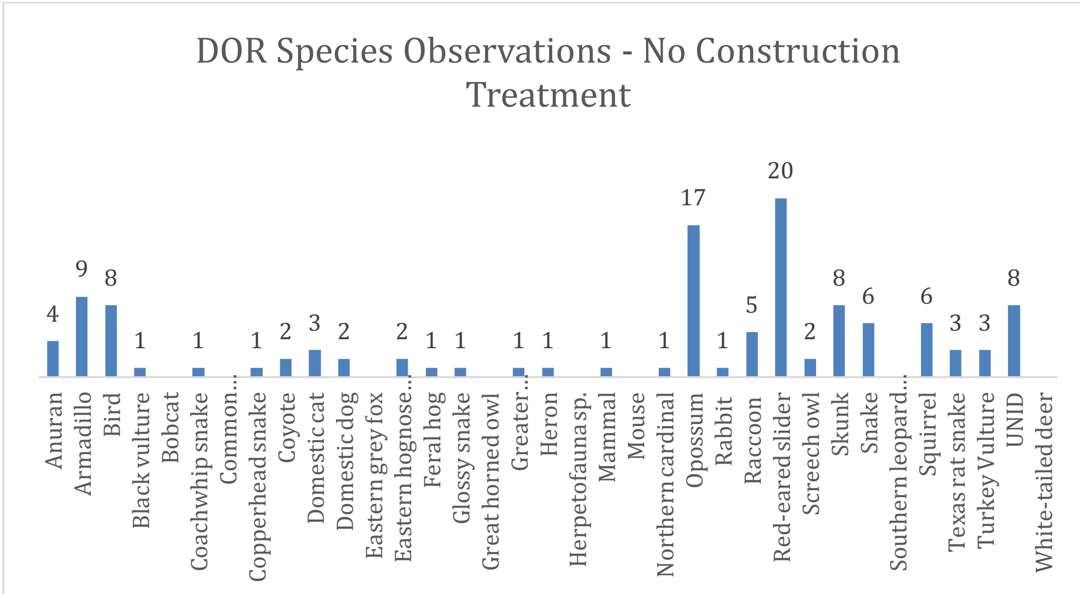

Figure 23. Wildlife mortalities observed within the 12.8 km section of US Highway 290 within the No Construction treatment. Species observations were collected from January 2016-May 2017. Graphical representations show the species observed in the No Construction treatment. Highest species observed were red-eared slider (*Trachemys scripta elegans*) and opossum (*Didelphis virginiana*).

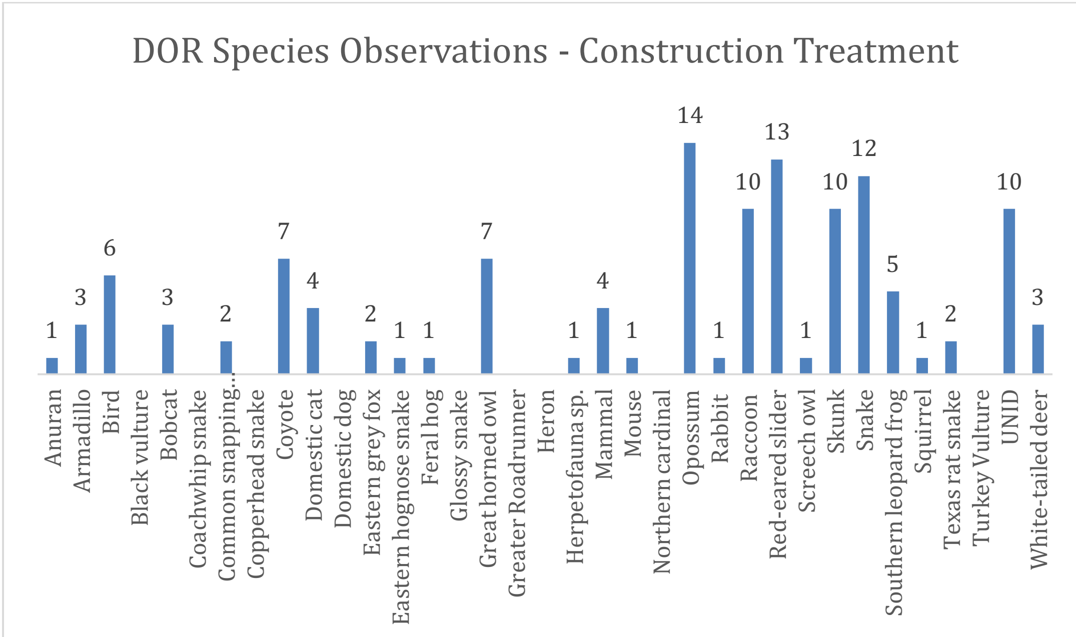

Figure 24. Wildlife mortalities observed within the 12.8 km section of US Highway 290 within the construction treatment. Species observations were collected from January 2016-May 2017. Graphical representations show the species observed in the Construction treatment. Highest species observed were red-eared slider (*Trachemys scripta elegans*) and opossum (*Didelphis virginiana*).

Figure 25. Distribution of wildlife mortality observations within the Highway 290 study area in Bastrop County, Texas. These are total observations of DOR surveys from January 2016 to May 2017. The teal markers represent the locations of the installed WCS. Wildlife mortalities were evenly distributed throughout the study area.

Figure 26. Screenshot from a video survey attempting to identify a wildlife mortality to the species level. The observation was able to be identified as a Skunk (*Mephitis mephitis*) based on its morphological characteristics.

Figure 27. Screenshot from a video survey attempting to identify a wildlife mortality to the species level. The observation was not able to be identified as a result of its position on the roadway. Animal carcass' positioned in the roadway are often continuously ran over by vehicles resulting in inability to identify the carcass in the video recording.

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